The Use of Physical and CFD Models to Improve Juvenile Fish Passage at The Dalles Dam, TDA, The Dalles, Oregon

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ABSTRACT

Among the Federal Columbia River Power System dams, The Dalles Dam (TDA) has the lowest juvenile salmonid survival rates. Therefore, improving fish survival through The Dalles Dam is a top priority for the Portland District, U.S. Army Corps of Engineers and Regional Resource Agencies (Region). The primary effort has been at the spillway, since that is where the majority of fish pass the dam. Field tests have been conducted at the spillway using live fish and surrogate or sensor fish in order to determine the causes of mortality. Potential sources of mortality include mechanistic injury due to excessive exposure to intense turbulence in the stilling basin and predation by northern pikeminnow and smallmouth bass in the tailrace. During 2002, the Corps of Engineers used the 1:80 general and 1:40 sectional physical model at Engineer Research and Development Center (ERDC) in Vicksburg, Mississippi to understand the spillway hydraulics that fish are exposed to, design features which would reduce fish exposure to the stilling basin environment, and to set up prototype testing scenarios. Physical and Computation Fluid Dynamics (CFD) models are being used to develop biological studies, to estimate velocities in predatory fish habitat areas and on the stilling basin shelf, and to evaluate the implication of changing features within the stilling basin which include a spillway wall, flow deflectors, baffle block removal, and raised tailwater elevation.

INTRODUCTION

The juvenile fish passage survival rate at The Dalles Dam (TDA) is the lowest on the Lower Columbia River and several studies are currently underway to identify ways to increase the survival. The process is iterative and uses biological testing to identify sources of injury and mortality. The biological results are evaluated and hypotheses are proposed. The physical and numerical models are then used to assess these hypotheses. If the models support a particular hypothesis, structural alternatives are proposed and evaluated in the models. For alternatives that appear promising, a full-scale prototype structure is built and biological testing is conducted to evaluate the alternatives in the field. If the prototype test is successful, the alternative is implemented. The iterative process is in the initial stages at TDA and one alternative (a spillwall) has moved to the forefront to be fast tracked. This paper will document the process used to: identify the biological issue, propose a hypothesis, test the hypothesis, develop alternatives, evaluate alternatives and develop an implementation plan.

PROJECT BACKGROUND

The Rivers and Harbor Act of May 17, 1950 authorized TDA Lock and Dam project, Figure 1. The initial project consisted of a navigation lock, spillway, powerhouse, adult fish passage facilities and various recreational facilities. The multi-purpose project is a part of the navigation system on the Columbia River and provides recreational and substantial hydropower benefits. The Dalles Dam is a concrete gravity and rockfill dam located within Klickitat County, Washington, on the Columbia River at River Mile 192. It is located 47 miles upstream of Bonneville Dam. It consists of 23 spillbays, which are 50 feet wide and can carry a spillway design flood of 2,290,000 cfs. The powerhouse consists of 2 fish units and 22 main turbine units and has a total hydraulic capacity of approximately 320,000 cfs. Construction work on TDA Lock and Dam was initiated on 18 February 1952. The project was initially flooded in 1957 and the last turbine unit was brought on line in 1971. TDA Lock and Dam was built on basalt; and during the design phase, a key design consideration was to minimize excavation costs. This resulted in TDA spillway exit channel having the shallowest tailrace of all of the projects on the Columbia River, Figure 2 and Table 1. This affects many aspects of the dam especially the energy dissipation characteristics. The tailwater at TDA is controlled by river flow and the operations at Bonneville Dam.

Adult fish passage facilities were incorporated into the original design and construction of the dam. Juvenile fish passage facilities were not originally designed or constructed as part of TDA. Downstream migrating juvenile fish were expected to pass via the turbine units or the spillway during high flow periods. During the early 1970's, the ice and trash sluiceway was identified as an effective juvenile bypass system; but its current capacity is 4,500 cfs. Operations to use the ice and trash sluiceway as a bypass system were refined from 1977-81; and since 1981, it has been operated daily during the juvenile salmon and steelhead out migration,

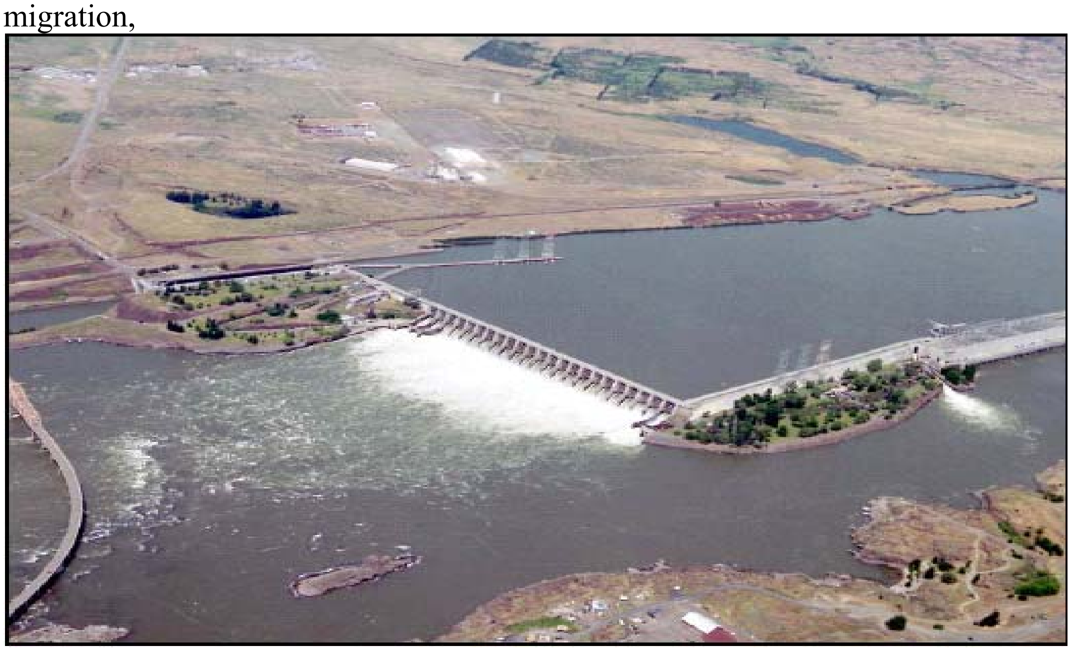

Figure 1. The Dalles Dam, The Dalles, Oregon

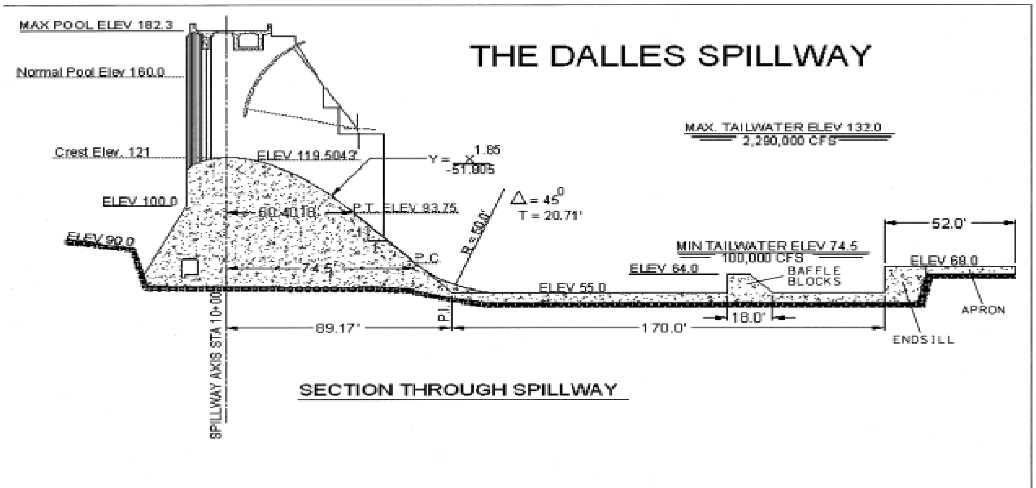

Figure 2. The Dalles Dam Spillway, Bay Locations

Lower Snake and Lower Columbia Rivers Stilling Basin Volumes					
Project	**Length**	**Normal TW**	**Floor El**	**Volume**	**Depth**
Lower Granite	188	638	580	10904	58
Lower Monumental	198	440	392	9504	48
Ice Harbor	176	340	304	6336	36
McNary	270	265	228	9990	37
John Day	185	160	114	8510	46
The Dalles	**170**	**78**	**55**	**3910**	**23**

Table 1 Comparison of the Stilling Basins Shallowness

April-November. In 1996, the ice and trash sluiceway operation switched from daytime hours to 24 hours per day. Since 1989, a proportion of the river has been spilled at TDA to provide an additional non-turbine juvenile passage route. Spill patterns, specifically designed to enhance juvenile fish passage, were first implemented in 1995. From 1995 to 1999, an adult fish spill pattern, crowned spill in the center of the spillway that tapers out at the end bays, was used during the daytime and a juvenile spill pattern, spill in the north bays, was used at night. The juvenile pattern was designed to keep juvenile salmonid migrants moving downstream and away from areas where piscivorous fish are known to reside (Shively et al. 1996; Martinelli and Shively 1997). The proportion of project discharge spilled during 1995-1999 fish passage seasons ranged from 30% to 69%. Since 2000, 40% of the total river discharge is spilled 24-hours per day from April 10 through August 31 except during the drought year of 2001; and, the juvenile fish passage pattern is used day and night.

INTRODUCTION TO THE DALLES SPILLWAY IMPROVEMENT STUDY PROCESS

This study has been a concurrent and iterative process of identifying biological fish survival concerns out at the dam, determining hydraulic characteristics with the physical and numerical models, determining alternatives, which reduce or eliminate these fish survival concerns.

BIOLOGICAL STUDIES

In 1995, Normandeau Associates (1996) evaluated juvenile salmon survival at TDA spillway using balloon-tagged fish that were released under a 3-bay operation. One key result from this study was that survival appeared to be low through the standard spillbay. Only 94% of the balloon tagged fish were recovered and survival through an existing bay was estimated at 95.5% (Normandeau et al. 1996). From 1997-2000, the National Marine Fisheries Service (NMFS) evaluated survival at TDA using passive integrated transponder (PIT) tagged fish. Their objective was to assess whether spillway passage survival under 64% spill was high; and if not, determine whether lower spill rates would improve survival. Based on 1997-2000 survival results, NMFS found that percent spill affected survival, with 30% spill resulting in higher survival than 64%. The 40% spill level used with the juvenile pattern in 2000 resulted in survival rates similar to those seen under the 30% spill levels tested in previous years (Dawley et al. 2000; Absolon et al. 2002). Although survival was improved at the lower spill percentages, it was still unacceptably low for a primary passage route. During the 2000 spillway evaluation, it was estimated that 80% of all spring migrants and 75% of all summer migrants passed TDA via the spillway (Beeman et al. 2001; Moursund et al. 2001). With such high spillway passage rates, the composite survival of fish passing all routes at TDA is heavily weighted toward spillway survival rates.

In 2000 - 2001, the Corps set out to design a survival study that would separate direct mortality due to spillway passage from indirect effects such as predation. The first step in the study design process was to use the 1:80 general physical model to determine the conditions and locations to release test fish. From this model work, it became evident that fish passing bays on the south side of the spillway could have a different exposure to the stilling basin than fish passing on the north side of the spillway. Flow is concentrated in the northern most bays, which draws flow from closed spill bays and the powerhouse. The flow is transported parallel to the spillway and turns at Bay 3 before moving downstream. The closer to the south edge of the spill pattern dye is introduced, the longer it is retained in the stilling basin and the further northward it is transported before moving downstream. The next step in the study design process was to determine the feasibility of using balloon-tag mark-recapture techniques (Mathur and Heisey 1996) to estimate direct survival and injury rates under a 40% spill operation at TDA. A limited number of balloon-tagged fish were released from a north spill bay (Bay 4) and two south spill bays (Bays 9 and 11). Autonomous sensor packages (sensor fish, Figure 3) were released and recaptured along with the balloon-tagged fish. The sensor fish is a self-contained electronic sensor capable of measuring and digitally recording pressure and triaxial acceleration. Sensors are housed in a 50.8 mm diameter by 190.5 long cylinders that weigh 355 g. The sensor fish has a slight negative buoyancy

(Carlson and Duncan 2003). They were used to assess the physical conditions that the balloon-tagged fish may have experienced in the stilling basin, and relate these conditions to survival and injury data. Also, radio-tagged juvenile salmon were released from the same spillway locations and monitored via an array of aerial and underwater antennas to assess lateral movement and retention time within the stilling basin.

Normandeau and Associates conducted the survival study and demonstrated that it was feasible to estimate the direct effects of spillway passage on juvenile salmonid survival and injury. The test was repeated for spring and summer conditions in 2002 with larger sample sizes and a tailrace reference group so that precise survival rates could be generated. Injury and survival rates for 2001 and spring 2002 are summarized in Table 2 below. Sample sizes in 2001 were small, and injury rate differences were not statistically significant. Total river discharge, spill discharge, and tailwater elevation were higher during the spring 2002 compared to 2001. This may explain differences in injury types observed between the two years: in 2001 there were more injuries that appeared to be related to strike (e.g. scrapes, bruises, abrasions) where in 2002 injuries appeared to relate to hydraulic shear (e.g. hemorrhaged eyes, torn opercula). One other major operation difference between 2001 and spring 2002 is that spill volumes were higher in the spring of 2002. This means that more bays were spilling in 2002 and hence the spill pattern from Bay 9 to Bay 4 would have been flatter than in 2001.

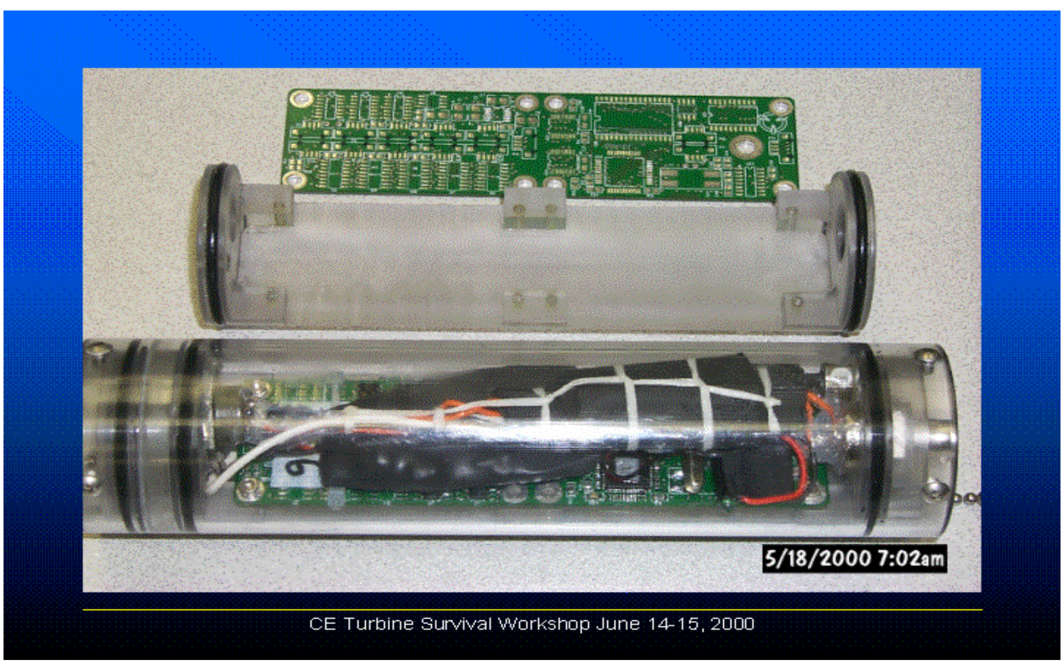

Figure 3. Sensor fish (Courtesy of Tom Carlson, Pacific Northwest National Laboratory

Table 2. Direct survival and injury rates from 2001 and Spring 2002 tests at TDA spillway (Normandeau 2001, Normandeau 2002)

	BAY 4	BAY 9	BAY 11, 13	Control
2001 Injury Rates (%)	1.8%	14.0%	11.5%	NA
2002 Injury Rates (%)	5.0%	5.0%	8.9%	1.0%
2002 Survival Rates %)	97.6%	97.4%	92.2%	NA

Radio telemetry monitoring in the stilling basin found evidence that radio tagged juvenile salmon passing Bays 9 and 11 moved laterally to the north before exiting the stilling basin. In addition, fish passing Bays 9 and 11 took longer to reach a downstream exit point than fish passing Bay 4 (Beeman et al. 2002). Sensor fish data revealed that stilling basin conditions varied between bays, with more severe conditions occurring in mid and south bays. There was evidence that sensor fish released through Bays 9, 11, and 13 spent more time in the stilling basin than those released through Bay 4. All of the sensor fish that were released in 2001 showed evidence of impacting concrete.

The balloon-tag study results determined that direct injury and mortality were attributable to passage through the stilling basin. Collectively, results from the three field study components suggest that lateral flow within the stilling basin can contribute to fish injury and mortality.

Another biological test was conducted in October of 2002 to estimate direct survival and injury rates for juvenile salmon passing through spill discharges of 4,500 cfs/bay and 12,000 cfs/bay and a low (76') tailwater. The purpose of this test was to determine what, if any, limits there were on spill discharge. Special spill patterns were developed using the numerical models and the 1:80 General Model to replicate the flow conditions in Bay 4 as though a spillwall was built between Bays 6 and 7. Balloon-tagged juvenile salmon were released through Bay 4 under the two discharges using the test spill patterns developed with the models. Results suggest that increasing discharge from 4,500 cfs/bay to 12,000 cfs/bay at a low tailwater does not increase injury or mortality rates. Another test is planned for June of 2003 under a high tailwater that will involve even higher discharges per bay (18,000 cfs to 21,000 cfs).

PHYSICAL MODELS

Physical models are used to evaluate and quantify the hydraulic characteristics of the flow at TDA. Of particular interest are the flow characteristics in and around the spillway. The 1:80 General Model (Figure 4) has been used to verify that the north bulked spill pattern sets up a lateral flow in the spillway. The prototype fish survival tests suggest that reducing the lateral flow, thus the retention time in the stilling basin will reduce the potential for spill passage related injury. The model was used to evaluate alternatives that would reduce the lateral flow. Operationally, different spill patterns were tried to minimize the lateral flow but the new spill patterns results in unacceptable egress conditions downstream of the spillway shelf and did not stop the lateral flow. Acceptable egress conditions are those in which the fish are sent to the deepest, fastest part of the river and not into predator habitat area. Spillway training walls were proposed and fast-tracked by the Region. The training wall(s) or spillwall(s) are essentially pier extensions out to the end sill. Spillwalls were tested in the 1:80 General Model with all spill being north of the spillwalls. Initial wall locations were determined by achieving downstream egress conditions like those generated by the north bulked spill pattern. During this modeling effort, spill was limited to 10,000 cfs per bay. This limitation required 2 walls and resulted in poor egress conditions at higher total river spill. Since the spring biological survival results were inconclusive, additional information was needed before installing spillwalls at The Dalles. With information received from the prototype test in October 2002, shifting one wall to the north and eliminating the other will be tested in the 1:80 General Model Spring 2003. While the Spillway wall work was being conducted, model studies were also being conducted in a 1:40 Spillway Sectional Model (Figure 5) at ERDC, which consists of the forebay and 3-1/2 bays. The model was used to evaluate stilling basin modifications (flow deflectors and baffle block removal). Velocities outside the stilling basin and pressures have been measured in this model as well as being used to evaluate energy dissipation under a variety of discharges and tailwater elevations.

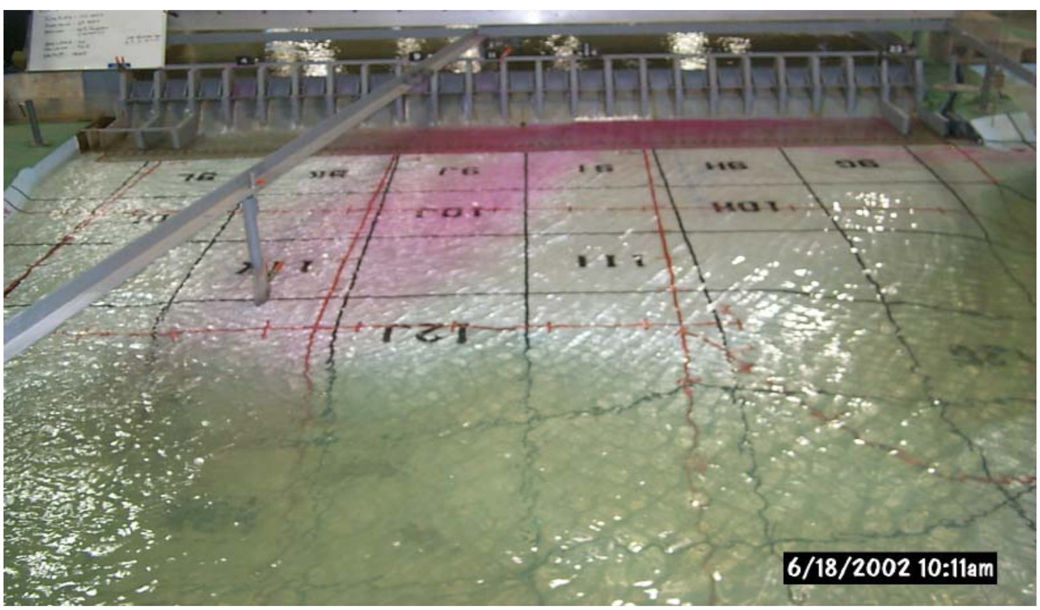

Figure 4-The 1:80 The Dalles General Model at ERDC, Looking upstream, Baseline Dye Release at Bay 23 Documenting Lateral Flow

Figure 5 The 1:40 The Dalles Dam Sectional Model at ERDC, 10,500 cfs/bay and TW=80

NUMERICAL MODELS

The physical models provide an opportunity to observe the flow characteristics and to make measurements in limited locations. Velocity measurements in the stilling basin of the physical models are not obtainable due to excessive turbulence. Three-dimensional transient models provide another tool to describe, define and evaluate the flow characteristics within the stilling basin. Several models have been developed: a 3-bay sectional model (similar to the 1:40 and 1:25 Sectional Models (under construction)) and a full tailrace model (similar to the 1:80 General Model). The numerical models can also be used to evaluate stilling basin modifications (deflectors, baffle block removal, etc), track water particle paths, and correlate to sensor fish data. In particular, numerical models were used to investigate the potential of increased flow per bay. Water particle paths recirculate within the stilling basin for 4,000 cfs at Bay 4 and a tailwater of 76.5 feet. Figure 6 shows water particle paths for 12,000 cfs out of Bay 4 and a tailwater of 76.5 feet; but in this case, the water particle paths exit directly out of the stilling basin.

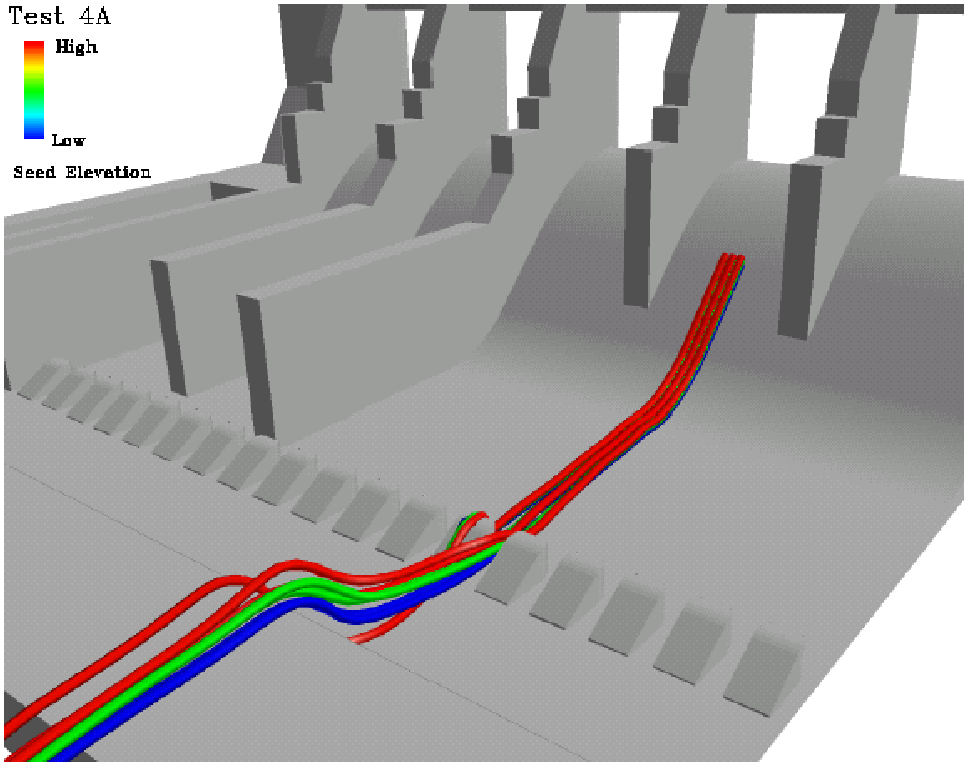

Figure 6- 12,000 cfs at Bay 4, TW=76.5'

FURTHER MODEL TESTS

The next round of model testing is being initiated to determine a wall location assuming that spill per bay can be increased. If a wall location can be identified and the May 2003 biological results confirm that a higher discharge per bay is acceptable, a prototype wall could be constructed by April of 2004.

CONCLUSIONS

In general, biological results at TDA have identified a survival issue at the spillway and formulated hypotheses as to why this is occurring. The 1:80 and 1:40 physical models at ERDC in Vicksburg, Mississippi were used to determine the hydraulics characteristics within the stilling basin and set up prototype fish survival testing scenarios out at the dam. However, data collection within these models is affected by turbulence. So numerical models are used to collect data in the stilling basin and several scenarios are ran to determine the ones that warrant further investigation in the physical models. The process is iterative and having all of the models available to test hypotheses and alternatives is invaluable.

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